Modeling the Topographic Influence on Cold Season Precipitation and ENSO Effects in the U.S. Pacific Northwest

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An important goal of the GEWEX Americas Prediction Project (GAPP) is "*to support scientific investigations that examine the orographic influence of the western Cordillera on cold season precipitation*". The U.S. Pacific Northwest (PNW) derives its water resources predominantly from cold season precipitation and storage in snowpack along the narrow Cascades range. An improved understanding of the orographic effects on precipitation is essential for significant advancement in the predictions of weather, climate, and hydrologic processes.

A three-tiered approach has been developed to systematically study cold season orographic precipitation in the PNW with the goal to improve predictions at the weather and climate time scales. Our approach includes: (1) case studies to determine the relationships between precipitation forecast skill and synoptic conditions, spatial resolution of topography and dynamical/physical processes, and cloud microphysics representations; (2) systematic analyses of seasonal climate simulations during El Nino and normal years to understand how synoptic and mesoscale circulations interact with the underlying topography to modulate the ENSO precipitation anomalies at the local and regional scales; and (3) extensive evaluation of the subgrid orographic precipitation scheme developed by Leung and Ghan to develop a foundation for using the subgrid method in weather and climate predictions.

During the past 6 months, we have begun the first two tasks listed above. Specifically, we examined the sensitivity of regional climate simulations to increasing spatial resolution via nesting by means of a 20-year simulation of the western U.S. at 40 km resolution and a 5-year simulation at 13 km resolution for the Pacific Northwest and California. Results show that the regional simulation at 40 km resolution shows a lack of precipitation along coastal hills, good agreements with observations on the windward slopes of the Cascades and Sierra, but over-prediction on the leeside and the basins beyond. Snowpack is grossly under-predicted throughout the western U.S. when compared against snotel observations. During winter, higher spatial resolution mainly improves the precipitation simulation in the coastal hills and basins. Along the Cascades and the Sierra Range, precipitation is strongly amplified at the higher spatial resolution. Higher resolution generally improves the spatial distribution of precipitation to yield higher spatial correlation between simulations and observations. During summer, higher resolution improves not only spatial distribution but also regional mean precipitation.

In the Olympic Mountain and along the Coastal Range, increased precipitation at the higher resolution reflects mainly a shift from light to heavy precipitation events. In the Cascades and Sierra, increased precipitation is mainly associated with more frequent heavy precipitation at higher resolution. Changes in precipitation from 40 km to 13 km resolution depend on synoptic conditions such as wind direction and moisture transport.

The use of higher spatial resolution improves snowpack more than precipitation. However our results suggest that accuracy in the snow simulation is also limited by factors such as deficiencies in the land surface model or biases in other model variables.

In a second study, we performed and analyzed a 20-year regional climate simulation driven by the NCEP/NCAR reanalyses for 1981-2000 to investigate how hydroclimate of the western U.S. is influenced by the strong interannual variability of atmospheric circulation associated with the El Nino-Southern Oscillation (ENSO). In the western U.S., precipitation anomalies during ENSO often show opposite and spatially coherent dry and wet patterns in the Northwest and California or vice versa. The role of orography in establishing mesoscale ENSO anomalies in the western U.S. is examined based on observed precipitation and temperature data at $1/8^o$ spatial resolution and a regional climate simulation at 40 km spatial resolution. Results show that during El Nino or La Nina winters, strong precipitation anomalies are found in northern California, along the southern California coast, and in northwest mountains such as the Olympic Mountain, the Cascades, and the Northern Rockies. These spatial features, which are strongly affected by topography, are surprisingly well reproduced by the regional climate simulation.

A spatial feature we investigated further is the positive-negative-positive precipitation anomaly found during El Nino years in the Olympic Mountain, and on the west side and east side of the Cascades in both observation and regional simulation. Figure 1 shows shows the observed, reanalyzed, and simulated composite El Nino anomalies of precipitation and temperature during 1980-2000. Anomalies are estimated based on the difference between mean El Nino year conditions and long term mean conditions. At the larger scale, the major patterns of precipitation variations are the dry anomalies in the Rockies and wet anomalies along the Pacific coast, especially in northern California. Temperature is generally cooler than normal in the south and warmer than normal by up to 2^oC towards the north. Areas with the largest wet anomalies are associated with small or near zero temperature anomalies in northern California. Areas with dry anomalies in the Rockies are associated with larger warm anomalies.

Although much of the climate variations in the western U.S. are captured at the larger scales, the effects of topography are not negligible. Most notably, the largest dry anomalies during El Nino years in the Northwest are found on the windward side of the Cascades and the Northern Rockies. The rest of the Northwest region typically shows very small anomalies except on the lee side of the mountains (e.g., northeast of the Olympic Mountain and the Cascades) where regions of positive anomalies are often found instead. The largest wet anomalies are located in northern California and along the Sierra and the southern coast.

The NCEP/NCAR reanalyses only captures the very broad spatial features of the temperature and precipitation anomalies, namely the gradual increasing warming trend towards the north, and the wet and dry anomalies along the coast and further inland. The regional simulation represents a clear improvement over the NCEP/NCAR reanalyses that provided the large-scale conditions for driving the simulation. It correctly captures the larger scale feature, namely the near north-south gradient in temperature and precipitation anomalies, as well as some of the mesoscale features associated with the complex terrain such as the positive-negative-positive anomalies on northeast Olympic Mountain and windward and lee side of the Cascades, and the large wet anomalies in northern California. The simulated precipitation anomalies in the southern Sierras are, however, too strong compared to observations. The temperature anomalies in the regional simulation are more realistic than the reanalyses, with stronger warming over Canada and stronger cooling in the Southwest.

Observed streamflows of river basins located in the areas of the Pacific Northwest areas are found to be consistent with the precipitation anomalies. The spatial distribution of the precipitation anomalies is investigated by relating flow direction and moisture to the orientation of mountains and orographic precipitation. In the west side of the north-south oriented Cascades Range, the increase in atmospheric moisture is not enough to compensate for the loss of orographic precipitation associated with a change in flow direction towards southwesterly during El Nino years. In California, both increase in atmospheric moisture and shift in wind direction towards southwesterly enhances precipitation along the Sierra, which is oriented northwest to southeast. The spatial signature of the interactions between large-scale circulation and topography may provide useful information for seasonal predictions or climate change detection.

Future studies will begin to further examine the effects of physics parameterizations such as cloud microphysics and turbulence transfer on the simulation of orographic precipitation and perform extensive evaluation of the subgrid orographic precipitation scheme developed by Leung and Ghan.

Publications:

Leung, L.R., and Y. Qian, 2003: The sensitivity of precipitation and snowpack simulations to spatial resolution via nesting in regions of complex terrain. *J. Hydrometeorology*, accepted.

Leung, L.R., Y. Qian, X. Bian, and A. Hunt, 2003: Hydroclimate of the western United States based on observations and regional climate simulation of 1981-2000. Part II: Mesoscale ENSO anomalies. *J. Climate*, in press.

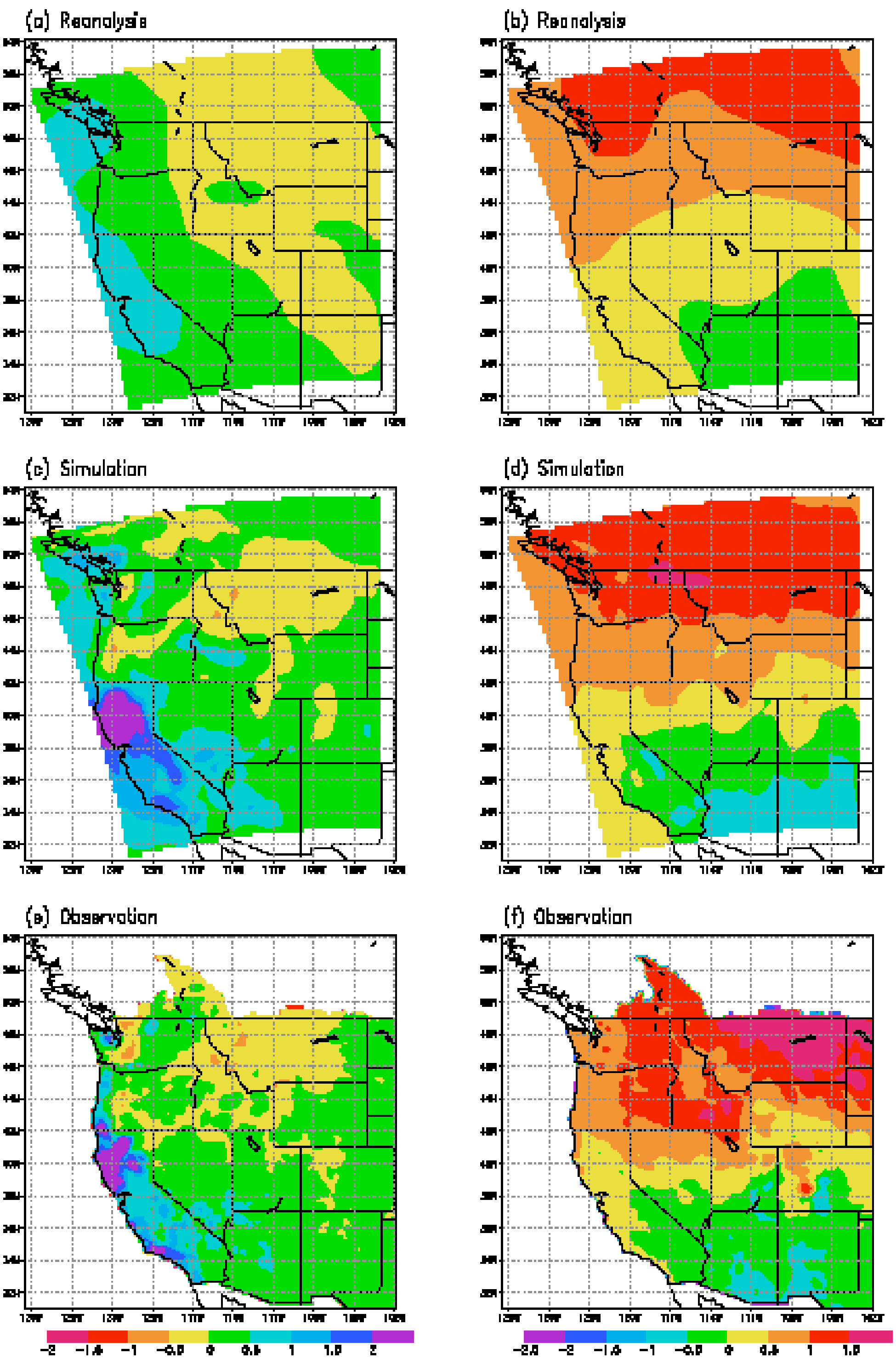

Figure 1. Anomalies of surface temperature (^{o}C) (right) and precipitation (left) during El Nino years between 1981-2000 based on NCEP/NCAR reanalyses (top), regional simulation (middle) and observation (bottom) for January-February-March.